Human System Risk at NASA

January 25, 2019

Erik Antonsen MD, PhD, FAAEM, FACEP
Assistant Director, Human Systems Risk Management

Conflicts of Interest Disclosure

1. Assistant Professor of Emergency Medicine, Baylor College of Medicine
2. Assistant Professor of Space Medicine, Center for Space Medicine
3. Attending Physician, Ben Taub General Hospital

4. Assistant Director, Human Systems Risk Management, NASA

I have financial interests in the above entities.

The opinions shared here are my own and not necessarily reflective of the above institutions.

The goal of this talk is to give an overview of how NASA approaches Human System Risks and how that relates to your work as researchers

Expect an overview of the following:

- **Big Big Picture**
- **Stakeholders**
- **Defining Likelihood and Consequencs**
- **Prioritizing Risks**
- **Relationship between Risks and Programs**
- **Integrating Between Risks**
- **Risk Stacking**
- **How do we burn down Risk? (OR why does your research matter?)**

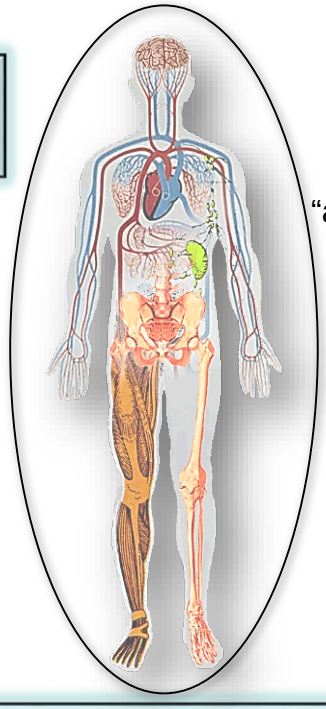
Human System Hazards – where Risks come from

Altered Gravity - Physiological Changes

Balance Disorders
Fluid Shifts
Cardiovascular Deconditioning
Muscle Atrophy
Bone Loss

Distance from earth

Drives the need for additional "autonomous" medical care capacity – cannot come home for treatment



Hostile/ Closed Environment

Vehicle Design
Environmental – CO_2 Levels, Toxic Exposures, Water, Food
Decreased Immune Function

Space Radiation

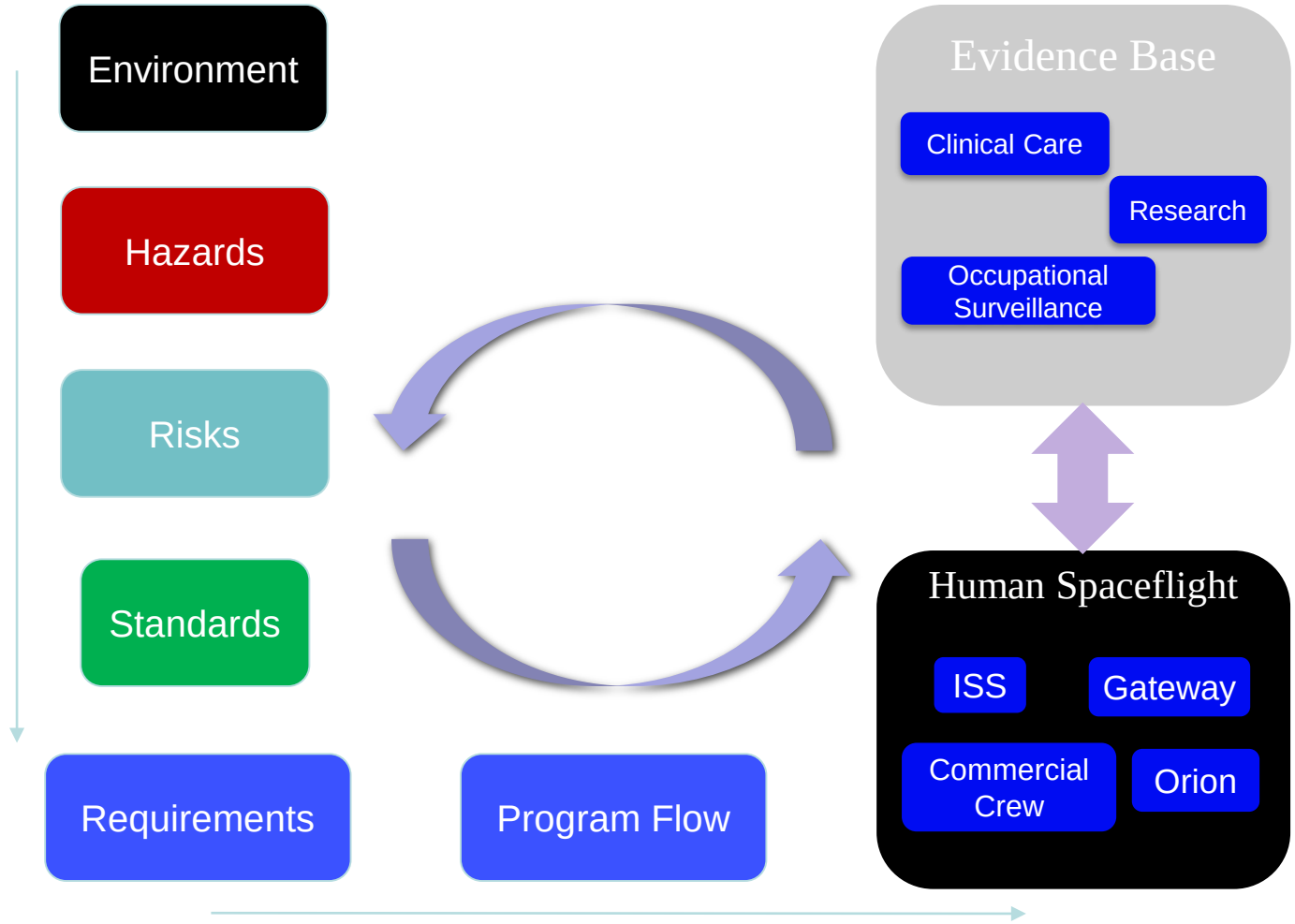
Acute In-flight effects
Long term cancer risk

Isolation & Confinement

Behavioral aspect of isolation
Sleep disorders
Team dynamics

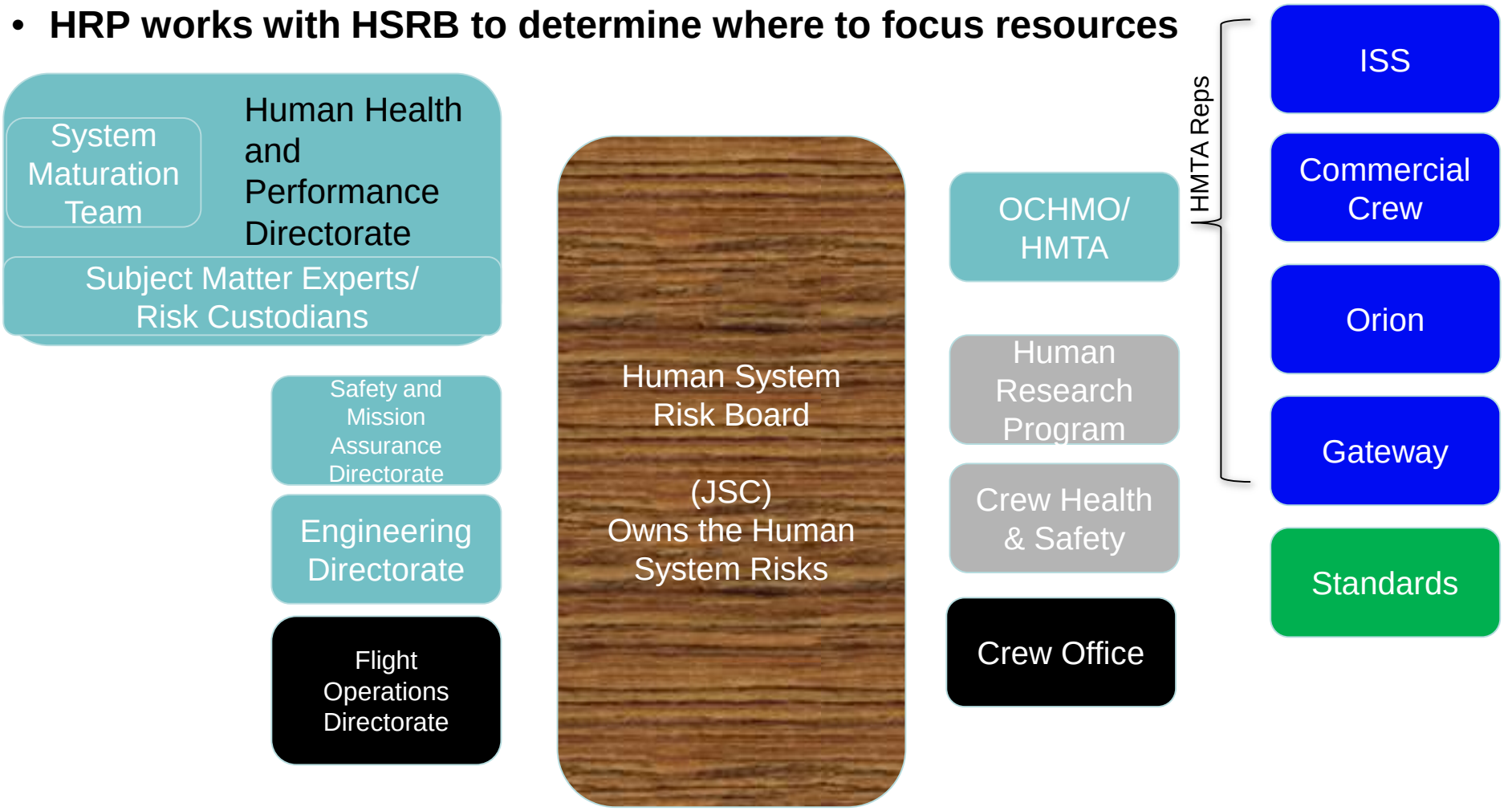
Human System Risks

The Big Big Picture



Who Cares about Risk?

- **Stakeholders sit at the HSRB table**
- **Human System Risks are owned by HMTA**
- **HRP works with HSRB to determine where to focus resources**



Human System Risks – Likelihood vs Consequence

Consequence
Mission Health and Performance (OPS)

High	Death or permanently disabling injury to one or more crew (LOC) OR Severe reduction of performance that results in loss of most mission objectives (LOM)
Medium	Significant injury, illness, or incapacitation – may affect personal safety OR Significant reduction in performance results in the loss of some mission objectives
Low	Minor injury/illness that is self-limiting OR Minor impact to performance and operations- requires additional resources (time, consumables)
Very Low	Temporary discomfort OR Insignificant impact to performance and operations - no additional resources required

Consequence
Long Term Health (post mission) (LTH)

High	Unknown and improbable return to baseline (requires drastic intervention surgery & therapy) OR Major impact on quality of life (permanent reduced function, premature death)
Medium	Return to near baseline requires extended medical intervention w/ known clinical methods/technologies (pharmaceuticals, etc.) OR Moderate impact on quality of life
Low	Return to baseline values within 1 year with nominal intervention (time, exercise, nutrition, lenses) OR Negligible effect on quality of life
Very Low	Return to baseline values within 3 months with limited intervention OR No effect on the quality of life

Consequence \ Likelihood	Low ≤0.1 %	Medium <1 %	High ≥1.0%
High	1 x 4	2 x 4	3 x 4
Medium	1 x 3	2 x 3	3 x 3
Low	1 x 2	2 x 2	3 x 2
Very Low	1 x 1	2 x 1	3 x 1

Likelihood

Quality of Life is defined as impact on day to day physical and mental functional capability and/or lifetime loss of years

CM = Countermeasure
LOC = Loss of Crew
LOM = Loss of Mission

Big Picture of Risks?

Human Spaceflight Risks	In Mission Risk - Operations						Post Mission Risk - Long Term Health					
	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/ Habitation	Deep Space Journey/ Habitation	Planetary Visit/ Habitation	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/ Habitation	Deep Space Journey/ Habitation	Planetary Visit/ Habitation
	6 Months	1 Year	1 Month	1 Year	1 Year	3 Years	6 Months	1 Year	1 Month	1 Year	1 Year	3 Years
Renal Stone Formation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation
Inflight Medical Conditions	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Requires Mitigation
Vision Alterations	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation
Cardiac Rhythm Problems	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring
Cognitive or Behavioral Conditions	Accepted with Monitoring	Requires Mitigation	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Requires Mitigation	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation
Space Radiation Exposure	Accepted	Accepted	Accepted	Accepted	Requires Mitigation / Data	Requires Mitigation / Data	Accepted with PELs	Accepted with PELs	Accepted with PELs	Requires Mitigation	Requires Mitigation	Requires Mitigation
Inadequate Food and Nutrition	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted / Optimize	Requires Mitigation
EVA Operations	Accepted	Accepted	Accepted / Optimize	Requires Mitigation	Accepted / Optimize	Requires Mitigation	Accepted	Accepted	Accepted / Optimize	Requires Mitigation	Accepted / Optimize	Requires Mitigation
Psychosocial Adaptation within a Team	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted with Monitoring
Inadequate Human-System Interaction Design	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Standard Refinement, May Require Mitigation	Standard Refinement, May Require Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
Unpredicted Effects of Medication	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

How do we relate Risks to Programs?

Operation Assessment Health and Performance Risks	Nominal Operations						Off Nominal/Emergency Conditions					
	ISS	Soyuz	SpaceX	Boeing	Orion	Gateway	ISS	Soyuz	SpaceX	Boeing	Orion	Gateway
Inflight Medical Care System											Limited ALS	Limited ALS
SANS			Seat Inclination									
Renal Stone Formation												
Radiation Exposure					Deep Space	Deep Space					Deep Space	Deep Space
Altered Immune Response												
Urinary Retention												
Sleep Loss			Thruster Firings									
Space Adaptation Back Pain												
Cardiovascular Disease/Cardiac Rhythm												
Behavioral Conditions												
Team Dynamics												
Ineffective Medications - Long Term Storage												
Food Supply, inadequate nutrition												
Muscle Loss			Water Landing	Water Landing	Water Landing				Water Landing	Water Landing	Water Landing	
Sensorimotor Alterations			Water Landing	Water Landing	Water Landing				Water Landing	Water Landing	Water Landing	
Aerobic Capacity			Water Landing	Water Landing	Water Landing				Water Landing	Water Landing	Water Landing	
Orthostatic Intolerance			Water Landing	Water Landing	Water Landing				Water Landing	Water Landing	Water Landing	
Bone Fracture			Water Landing	Water Landing	Water Landing				Water Landing	Water Landing	Water Landing	
Injury from Dynamic Loads												
Host Microorganism Interaction												
Toxic Exposure												
Acute and Chronic Carbon Dioxide Exposure						2 mmHg			Emergency Scenarios	Emergency Scenarios		
Hypoxia												
Lunar (Celestrial) Dust Exposure	N/A	N/A	N/A	N/A	TBD		N/A	N/A	N/A	N/A	TBD	
EVA/LEA - suit design									Suit PSI	Suit PSI		
Decompression Sickness									Suit PSI	Suit PSI		
Human Centric Desgin			Time on back	Time on back	Time on back	Limited NHV			Hatch Design	Hatch Design	Hatch Design	
Injury from Sunlight Exposure												
Hearing Loss Related to Spaceflight												
Risk of electrical shock												

Minimal Impact to Crew Health and Performance. Standards and requirements generally being met		Noticeable impact to Crew Health and Performance. Standards and requirements not being met.		Significant Impact to Crew Health and Performance. Standards and requirements not being met	

Example Risk Matrix from Exploration Systems Directorate

- Minor Injury – Based on Soyuz
- Moderate Injury Scenario – expect Orion to have harder landings

LIKELIHOOD RATING	
5 Very High	Qualitative: Nearly certain to occur. Controls have little or no effect. **Quantitative: 10^{-1}<P** (for risks with primary consequence on Human Safety - Personnel) or P>50% (for risks with primary consequence on Cost, Schedule, or Performance).
4 High	Qualitative: Highly likely to occur. Controls have significant uncertainties. **Quantitative: 10^{-2}<P≤10^{-1}** (for risks with primary consequence on Human Safety-Personnel) or 33%<P≤50% (for risks with primary consequence on Cost, Schedule or Performance)
3 Moderate	Qualitative: May occur. Controls exist with some uncertainties. Quantitative: 10^{-3}<P≤10^{-2} (for risks with primary consequence on Human Safety-Personnel) or 10%<P≤33% (for risks with primary consequence on Cost, Schedule, or Performance)
2 Low	Qualitative: Not likely to occur. Controls have minor limitations/uncertainties. Quantitative: 10^{-4}<P≤10^{-3} (for risks with primary consequence on Human Safety-Personnel) or 1%<P≤10% (for risks with primary consequence on Cost, Schedule, or Performance)
1 Very Low	Qualitative: Very unlikely to occur. Strong Controls in Place. Quantitative: P≤10^{-5} (for risks with primary consequence on Human Safety-Personnel) or P≤1% (for risks with primary consequence on Cost, Schedule, or Performance).

ESD Risk Score Card

LIKELIHOOD \ CONSEQUENCE	1	2	3	4	5
5	10	16	20	23	25
4	7	13	18	22	24
3	4	9	15	19	21
2	2	6	11	14	17
1	1	3	5	8	12

Timeframe To Initiate Handling Strategy	
Near	0 to 3 months
Mid	3 to 9 months
Far	> 9 months

CONSEQUENCES		1	2	3	4	5
SAFETY	Personnel	Minor injury not requiring first-aid treatment, minor crew discomfort	Injury requiring first-aid treatment, moderate crew discomfort	Injury, illness or incapacitation requiring emergency or hospitalization treatment	Severe injury or illness requiring extended hospital/Medical treatment	Loss of life or permanently disabling injury
	Facilities, equipment, assets	Minor damage or non-essential flight assets	Minor damage to Program Critical assets, Major damage to non-essential assets	Minor damage to flight/ Ground assets, Major damage to Program critical assets, or loss of non-essential assets	Loss of mission, Major damage to Flight/Ground Assets; doesn't meet criteria for catastrophic hazard, or Loss of Program Critical Asset	Loss of Flight/Ground Assets or Loss of vehicle prior to completing its mission
	Environ-mental	Negligible OSHA/ EPA violation – non reportable	Minor reportable OSHA/EPA violation	Moderate OSHA/EPA violation which requires immediate remediation	Major OSHA/EPA violation causing temporary stoppage	Serious or repeat OSHA/EPA violations resulting in action terminating Program
PERFORMANCE	Requirements	Negligible impact to requirements/ design margins	Minor impact to requirements/ design margins	Moderate impact to requirements/design	Major impact to requirements/design margins	Technical goals not achievable with existing engineering capabilities/technologies
	Operations	Negligible impact to mission operations	Minor impact to operations – workarounds available	Moderate impact to operations – workarounds available	Failure to achieve major mission objectives	Contingency Abort
	Supportability	Temporary usage loss or LOCM of non-flight critical asset	Permanent usage loss or LOCM of non-flight critical asset	Temporary usage loss or LOCM of major element(s) of flight vehicle or ground facility	Permanent usage loss or LOCM of major element(s) of flight vehicle or ground facility	Inability to support further flight operations
COST		≤$100K	>$100K but ≤$1M	>$1M but ≤$10M	>$10M but ≤$100M	>$100M
SCHEDULE		Negligible schedule impact	Minor overall schedule impact (no impact to critical path)	≤1 month impact to critical path/milestones	>1 and ≤6 month impact to critical path/milestones	>6 month impact to critical path/milestones or possible Program cancellation

Translating Program and HMTA Risk Posture Updates

Health and Performance Risks	Nominal Operations						Off Nominal/Emergency Conditions					
	ISS	Soyuz	SpaceX	Boeing	Orion	Gateway	ISS	Soyuz	SpaceX	Boeing	Orion	Gateway
Inflight Medical Care System											Limited ALS	Limited ALS
SANS			Seat Inclination									
Renal Stone Formation												
Radiation Exposure					Deep Space	Deep Space					Deep Space	Deep Space
Altered Immune Response												
Urinary Retention												
Sleep Loss			Thruster Firings									
Space Adaptation Back Pain												
Cardiovascular Disease/Cardiac Rhythm												
Behavioral Conditions												
Team Dynamics												
Ineffective Medications - Long Term Storage												
Food Supply, inadequate nutrition												
Muscle Loss			Water Landing	Water Landing	Water Landing				Water Landing	Water Landing	Water Landing	
Sensorimotor Alterations			Water Landing	Water Landing	Water Landing				Water Landing	Water Landing	Water Landing	
Aerobic Capacity			Water Landing	Water Landing	Water Landing				Water Landing	Water Landing	Water Landing	
Orthostatic Intolerance			Water Landing	Water Landing	Water Landing				Water Landing	Water Landing	Water Landing	
Bone Fracture			Water Landing	Water Landing	Water Landing				Water Landing	Water Landing	Water Landing	
Injury from Dynamic Loads												
Host Microorganism Interaction												
Toxic Exposure												
Acute and Chronic Carbon Dioxide Exposure						2 mmHg			Emergency Scenarios	Emergency Scenarios		
Hypoxia												
Lunar (Celestrial) Dust Exposure	N/A	N/A	N/A	N/A	TBD		N/A	N/A	N/A	N/A	TBD	
EVA/LEA - suit design									Suit PSI	Suit PSI		
Decompression Sickness									Suit PSI	Suit PSI		
Human Centric Desgin			Time on back	Time on back	Time on back	Limited NHV			Hatch Design	Hatch Design	Hatch Design	
Injury from Sunlight Exposure												
Hearing Loss Related to Spaceflight												
Risk of electrical shock												

Minimal Impact to Crew Health and Performance. Standards and requirements generally being met

Noticeable impact to Crew Health and Performance. Standards and requirements not being met.

Significant Impact to Crew Health and Performance. Standards and requirements not being met

Commercial Crew (ISS)

Likelihood \ Consequence	1	2	3	4	5
5	15	10	6	3	1
4	19	14	9	5	2
3	22	18	13	8	4
2	24	21	17	12	7
1	25	23	20	16	11

Orion (Gateway)

LIKELIHOOD \ CONSEQUENCE	1	2	3	4	5
5	10	16	20	23	25
4	7	13	18	22	24
3	4	9	15	19	21
2	2	6	11	14	17
1	1	3	5	8	12

HMTA

	Low ≤0.1 %	Medium <1 %	High ≥1.0%
High	1 x 4	2 x 4	3 x 4
Medium	1 x 3	2 x 3	3 x 3
Low	1 x 2	2 x 2	3 x 2
Very Low	1 x 1	2 x 1	3 x 1

Likelihood

Soyuz ISS

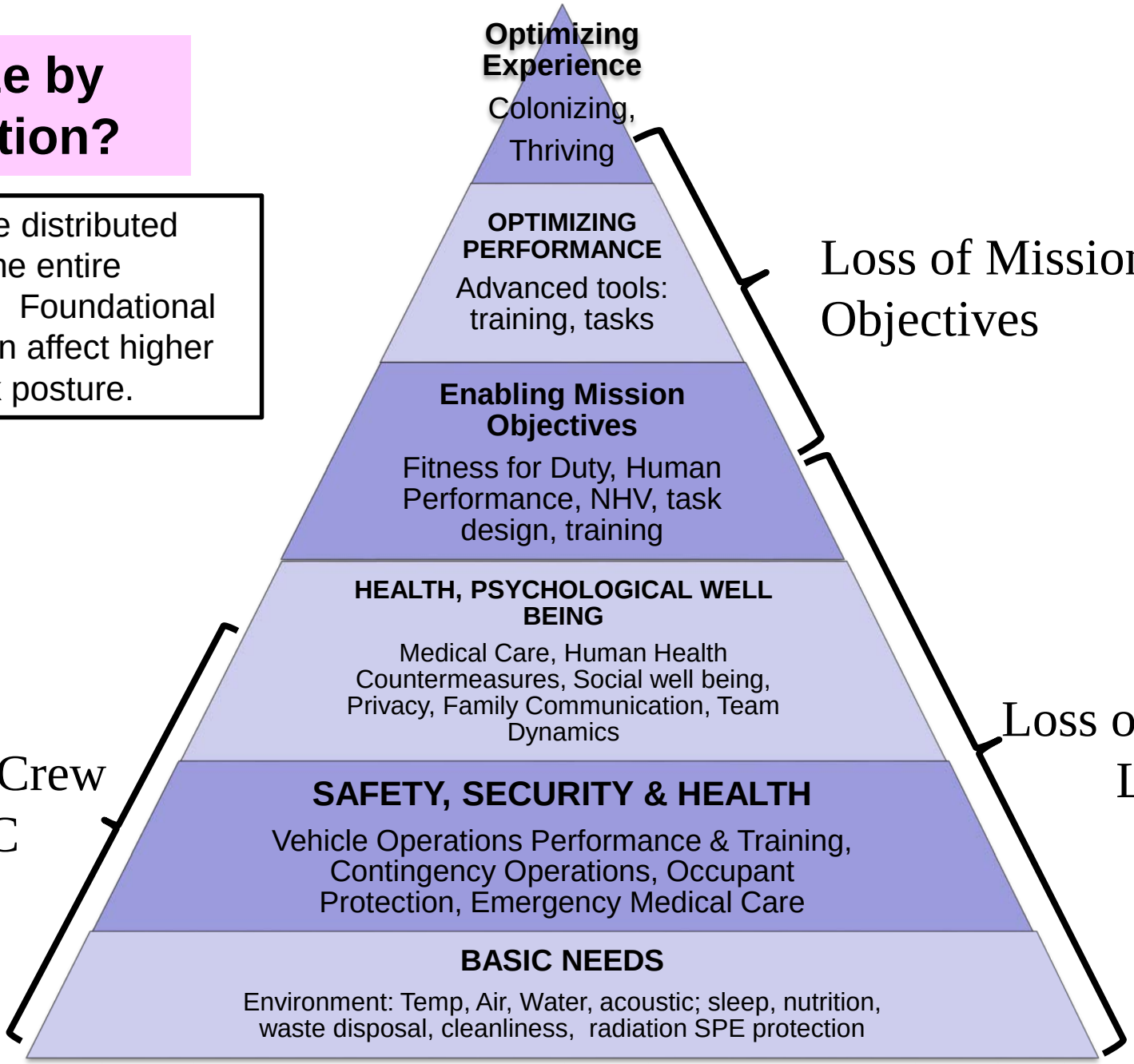
Prioritize by Color?

	In Mission Risk - Operations						Post Mission Risk - Long Term Health					
Human Spaceflight Risks	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/ Habitation	Deep Space Journey/ Habitation	Planetary Visit/ Habitation	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/ Habitation	Deep Space Journey/ Habitation	Planetary Visit/ Habitation
	6 Months	1 Year	1 Month	1 Year	1 Year	3 Years	6 Months	1 Year	1 Month	1 Year	1 Year	3 Years
Renal Stone Formation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation
Inflight Medical Conditions	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Requires Mitigation
Vision Alterations	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation
Cardiac Rhythm Problems	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring
Cognitive or Behavioral Conditions	Accepted with Monitoring	Requires Mitigation	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Requires Mitigation	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation
Space Radiation Exposure	Accepted	Accepted	Accepted	Accepted	Requires Mitigation / Data	Requires Mitigation / Data	Accepted with PELs	Accepted with PELs	Accepted with PELs	Requires Mitigation	Requires Mitigation	Requires Mitigation
Inadequate Food and Nutrition	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted / Optimize	Requires Mitigation
EVA Operations	Accepted	Accepted	Accepted / Optimize	Requires Mitigation	Accepted / Optimize	Requires Mitigation	Accepted	Accepted	Accepted / Optimize	Requires Mitigation	Accepted / Optimize	Requires Mitigation
Psychosocial Adaptation within a Team	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted with Monitoring
Inadequate Human-System Interaction Design	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Standard Refinement, May Require Mitigation	Standard Refinement, May Require Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted

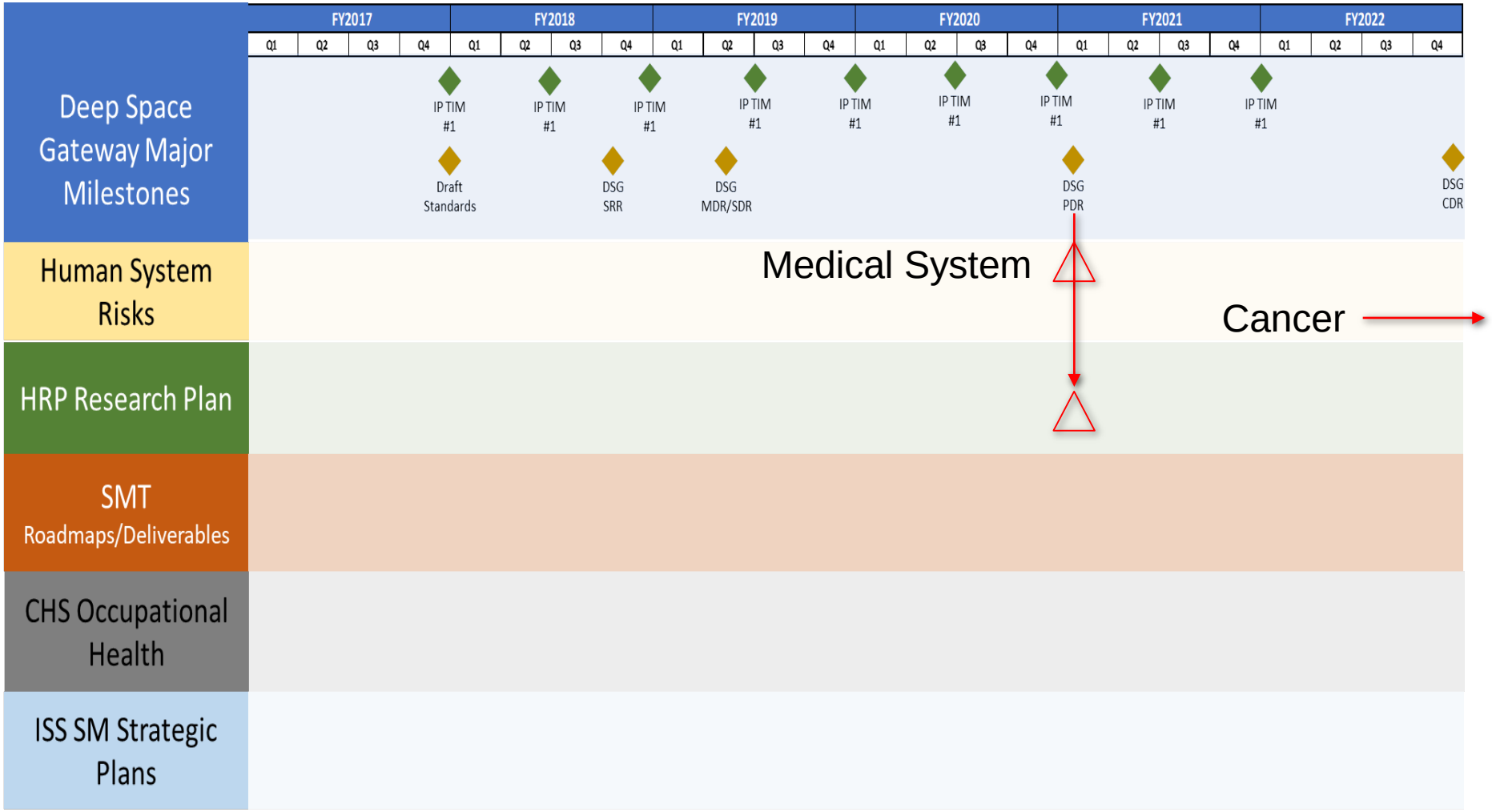
NASA Human System Risk Relationships

Prioritize by Foundation?

Risks are distributed across the entire pyramid. Foundational Risks can affect higher level risk posture.



Prioritize by Need Date?



Prioritizing Risk

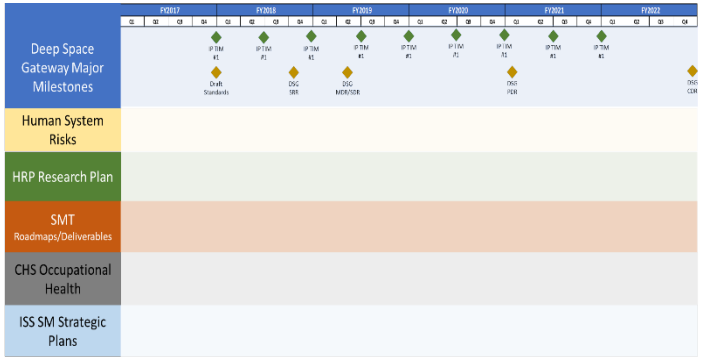
When you ask what are the top Risks, it depends on all these factors as well as the mission you are concerned with.

- **Risk Color**

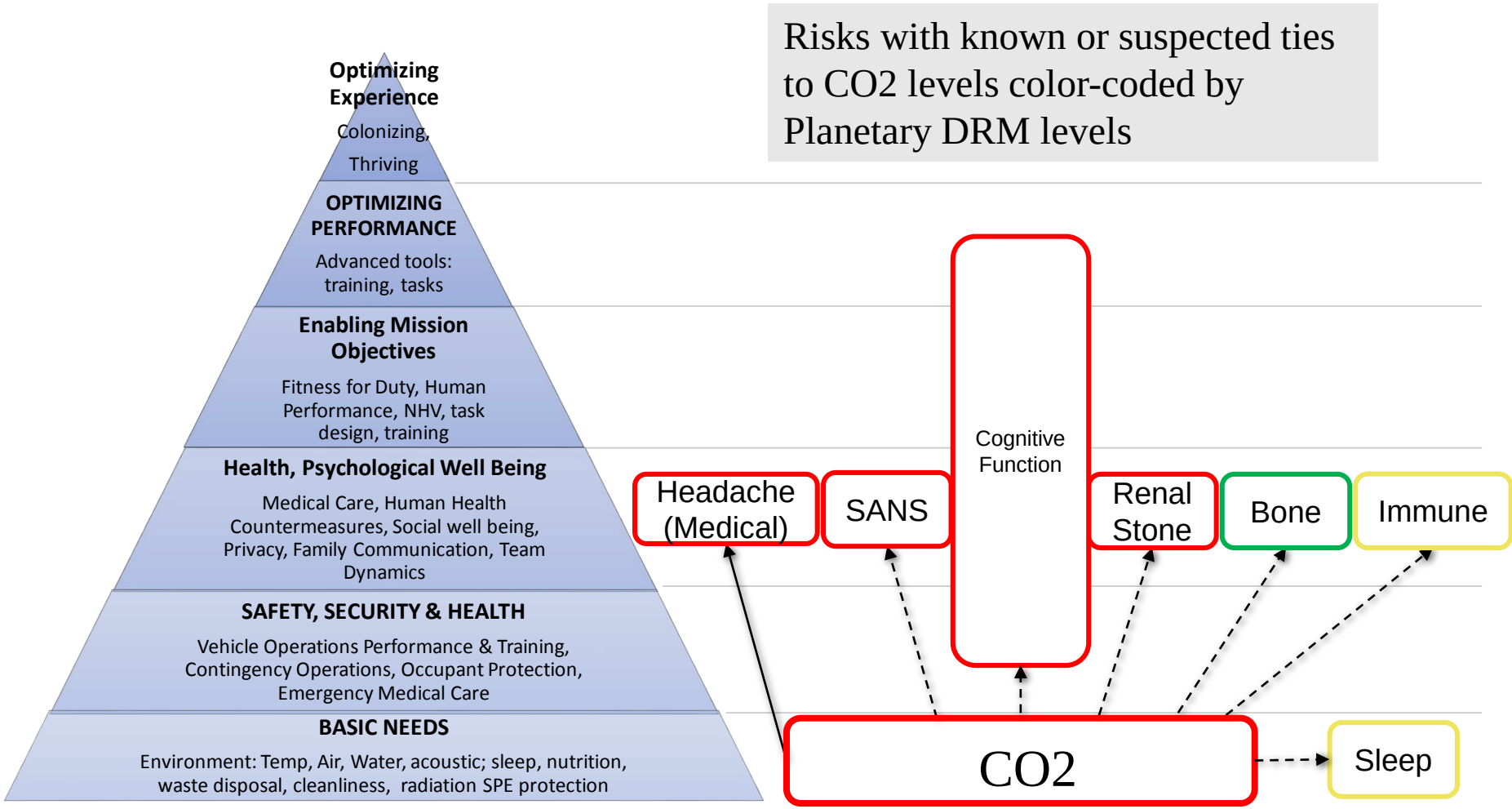
Human Spaceflight Risks	In Mission Risk - Operations						Post Mission Risk - Long Term Health					
	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/ Habitation	Deep Space Journey/ Habitation	Planetary Visit/ Habitation	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/ Habitation	Deep Space Journey/ Habitation	Planetary Visit/ Habitation
	6 Months	1 Year	1 Month	1 Year	1 Year	3 Years	6 Months	1 Year	1 Month	1 Year	1 Year	3 Years
Renal Stone Formation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation
Inflight Medical Conditions	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Requires Mitigation
Vision Alterations	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Requires Mitigation	Requires Mitigation
Cardiac Rhythm Problems	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring
Cognitive or Behavioral Conditions	Accepted with Monitoring	Requires Mitigation	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Requires Mitigation	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation
Space Radiation Exposure	Accepted	Accepted	Accepted	Accepted	Requires Mitigation / Data	Requires Mitigation / Data	Accepted with PELs	Accepted with PELs	Accepted with PELs	Requires Mitigation	Requires Mitigation	Requires Mitigation
Inadequate Food and Nutrition	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Accepted / Optimize	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted / Optimize	Requires Mitigation
EVA Operations	Accepted	Accepted	Accepted / Optimize	Requires Mitigation	Accepted / Optimize	Requires Mitigation	Accepted	Accepted	Accepted / Optimize	Requires Mitigation	Accepted / Optimize	Requires Mitigation
Psychosocial Adaptation within a Team	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Requires Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted with Monitoring
Inadequate Human-System Interaction Design	Accepted with Monitoring	Accepted with Monitoring	Accepted with Monitoring	Standard Refinement, May Require Mitigation	Standard Refinement, May Require Mitigation	Requires Mitigation	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted

- **Risk Category**

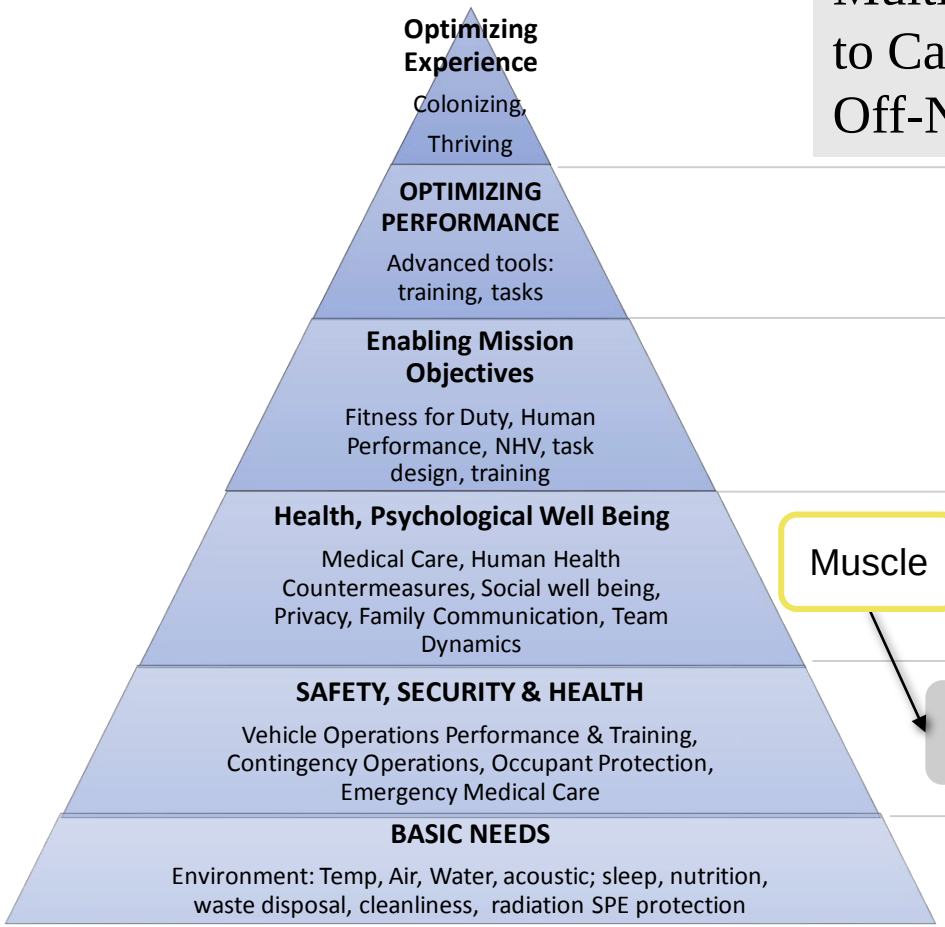
- **Risk Need Date**



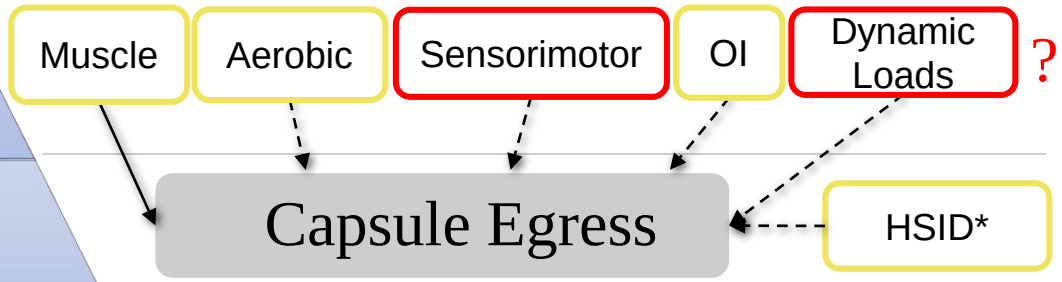
Integrating Between Risks – Foundational vs. Dependent



Integrating Between Risks – Operational Endpoints

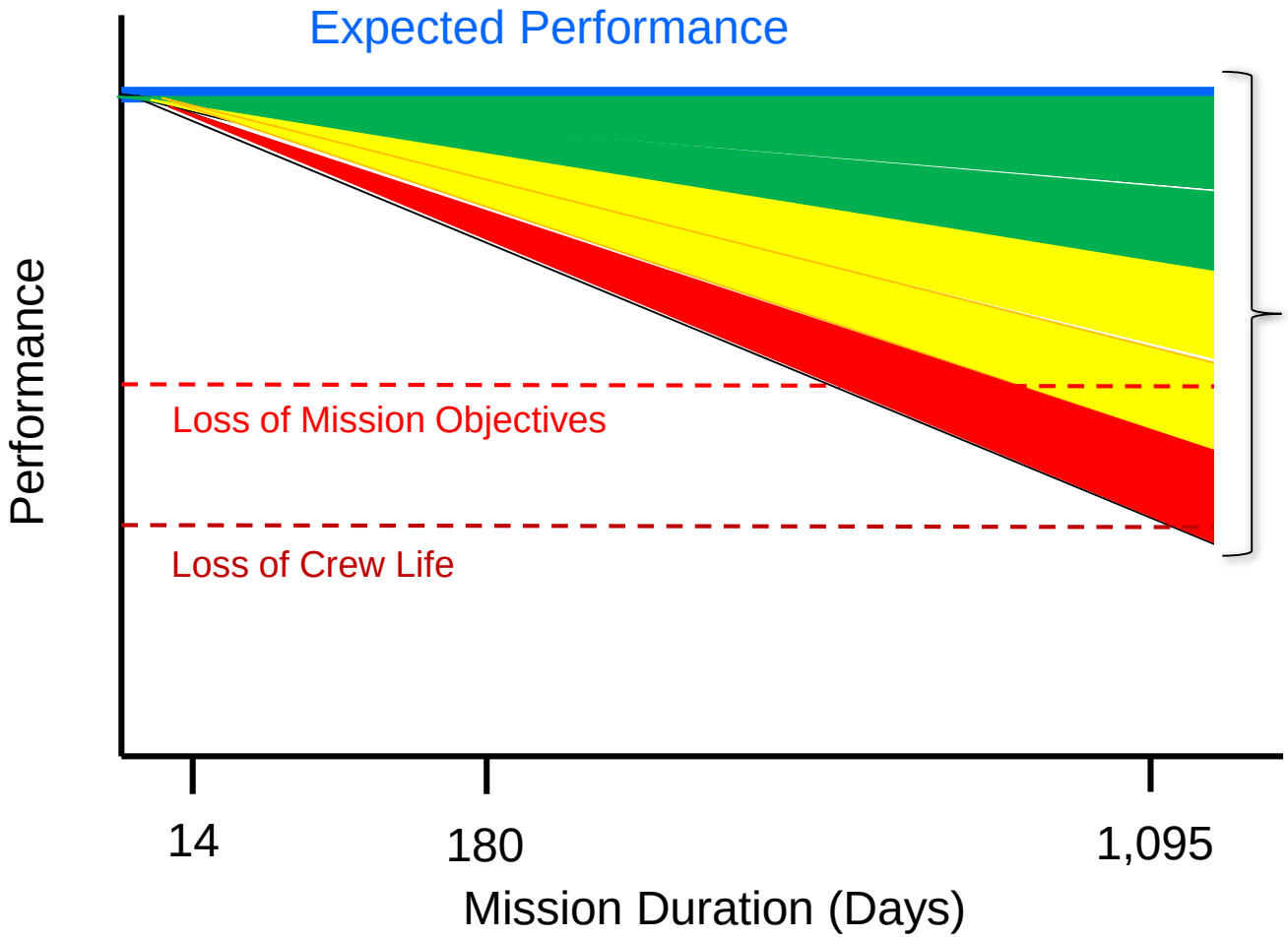


Multiple Risks contribute to ability to Capsule Egress in Emergency & Off-Nominal Situations



(*) HSID includes “Training” and contingency ground operations

Risks to Health & Human Performance won't occur in isolation



Factors Affecting Performance

- Physical Deconditioning
- Chronic Radiation Effects
- Depression/Team Dynamics
- Loss of Real Time support
- Insufficient Medical Capability

Where are the red lines and when will we hit them?

How do we Burn Down Risk?

High value research accomplishes one or more of the following:

- **Characterize or Understand the Risk**
- **Prevent risk scenarios from occurring (Hazard Control)**
- **Consequence Reduction (Risk Mitigation)**
- **Improve Margin**
- **Acceptance of Risk Levels**

Explanations can be found in the Risk Custodian Handbook

Backup